# A new EAS hybrid experiment in Tibet

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***Abstract*. A new hybrid experiment has been started by ASgamma experiment at Tibet, China, that consists of a low threshold burst-detector-grid (YAC, Yangbajing Air Shower Core array), air-shower array (AS) and old burst detector (BD). The first step of YAC, called "YAC-I", contains 16 detector units and observes high energy electromagnetic particles in AS cores within several meters from the shower axis, AS array measures the total energy and the arrival direction of air showers, and BD observes number of burst events. YAC-I is used to check hadronic interaction models currently used for air-shower simulations such as QGSJET I, II, Sibyll and EPOS etc through the multi-parameter measurement. We have successfully taking data from April 2009. The preliminary data analysis shows that this hybrid experiment (Tibet-AS+YAC1+BD) is powerful for this physics goal.**

***Keywords*: Cosmic ray, hardronic interaction, Air shower**

## I. INTRODUCTION

The study of the chemical composition over 100 TeV is made by indirect observations and has to rely on the observation of air showers (AS) produced by primary particles. There are two points which prevent the composition study. One is the primary composition dependence of the AS development. This dependence can be partly eliminated by choosing the observation site at high altitudes and also using an appropriate zenith angle cut to observe the shower near its maximum. The second point is the interaction model dependence. The hadronic interaction models used in any Monte Carlo codes were built based on some theoretical scenario that was checked by accelerator experiments only up to the hadron collider energies and extrapolated to the higher energies. It is noted that discrepant results on the studies of the cosmic ray composition at the knee energy region were reported by several recent cosmic ray experiments [1], [2].

Therefore, it is still a topic of debate how much of the discrepancy comes from the experimental systematic errors and how much, from uncertainties in the modeling used to describe the shower development. Thus, more checking and improvements on the hadronic interaction models are necessary. For the development of the air showers, the most forward region of the produced secondaries in the hadronic interactions is important, where, although it contains very few particles, a large fraction (say, more than 90%) of the collision energy is carried. This region can be studied by observing the high energy electromagnetic component at the air shower core.

Among many model parameters, some important features for cosmic-ray propagation : (1) inelastic cross section, (2) multiplicity distribution and (3) distribution of Feynman parameter. The difference of these features in models QGSJET01 and SIBYLL2.1, which are frequently used in AS simulation, can be summarized as follows. At the knee energy range, the difference of P-Air inelastic cross section, which determines the longitudinal development of AS, is rather small being a few % between SIBYLL model (higher) and QGSJET model (lower). The multiplicity distribution also determines how rapidly primary energies are dissipated by multiple production. QGSJET shows higher probability of high multiplicity events than SIBYLL at PeV, leading to the faster dissipation of the primary energy, namely lower secondary flux at a given energy. The difference of Feynman parameter distributions in two models is that SIBYLL model has a little harder meson production spectrum than QGSJET that leads to a larger difference in backward region which is related to the number of AS muons [3].

Therefore we propose a new hybrid experiment to test on currently used interaction models by observing AS cores at about *10 TeV where the primary composition is better known [4], [5]. We may directly use it as input to avoid the interruption induced by the uncertain primary composition, as in the case at the knee energy region.

In this paper, an overview on the new hybrid experiment(Tibet-III+YAC-I+BD) and first results are presented.

## II. NEW HYBRID EXPERIMENT

The new hybrid experiment consists of YAC(Yangbajing Air shower Core detector), burst detectors (BDs) and the Tibet-III air-shower array (AS). The first step called "YAC-I", has been successfully operating at Yangbajing (90.522° E, 30.102° N, 4,300 m above sea level) in Tibet, China, since April 2009 as shown in Fig. 1.

YAC-I consists of 16 YAC detectors of the size 40 cm × 50 cm, covering an area about 10 $m^2$, is used to check hardronic interaction models (Fig. 1). The second and the third step of future plan are called "YAC-II" and "YAC-III", respectively. YAC-II and YAC-III are used to obtain the individual component spectra of primary cosmic rays in a wide range over 3 decades between 100 TeV and $10^{17}$ eV in the near future.

YAC-I has the same design of the YAC-II and YAC-III, which is originally designed for the observation of the heavy component at the knee [8]. The basic structure of each YAC unit consists of lead plates of 3.5 cm (7 r.l.) thick and a scintillation counter which detects the burst size induced by high energy electromagnetic component at the air-shower core (Fig. 1). The burst size threshold is set to 100 particles which corresponds to 30 GeV of electromagnetic component incident upon a detector. Wide dynamic range between 1 MIP and $10^6$ MIPs (Minimum Ionization Particles) is covered by 2 PMTs [9]. The only difference between YAC-I and YAC-II is in the spacing. For the current purpose all detector units should be placed as densely as possible (YAC-I: low energy mode). But for realistic reason some non-zero spacing is necessary. In this experiment, a 28 cm crosswise spacing and 18 cm longitudinal spacing between two neighboring detectors is taken.

The AS array has 733 scintillation detectors (0.5 $m^2$). Fast-timing detectors are placed with 7.5 m spacing and density detectors are placed with 15 m spacing as shown in Fig. 1. The AS array is used to measure the shower size and the arrival direction of each air shower. Any four-fold coincidence of the FT detectors is used as the trigger condition for air-shower events. The air-shower direction can be estimated with an error smaller than 1°. The primary energy of each event is determined by the shower size ($N_e$). The energy resolution is estimated to be 17% at energies around $10^{15}$ eV by our simulation [6], almost independent of the interaction models used. The YAC-I and the BDs are constructed near the center of the AS array [2], [7] as shown by the white square in Figure 1, and are used to detect high-energy air shower cores accompanied by air showers induced by primary cosmic rays.

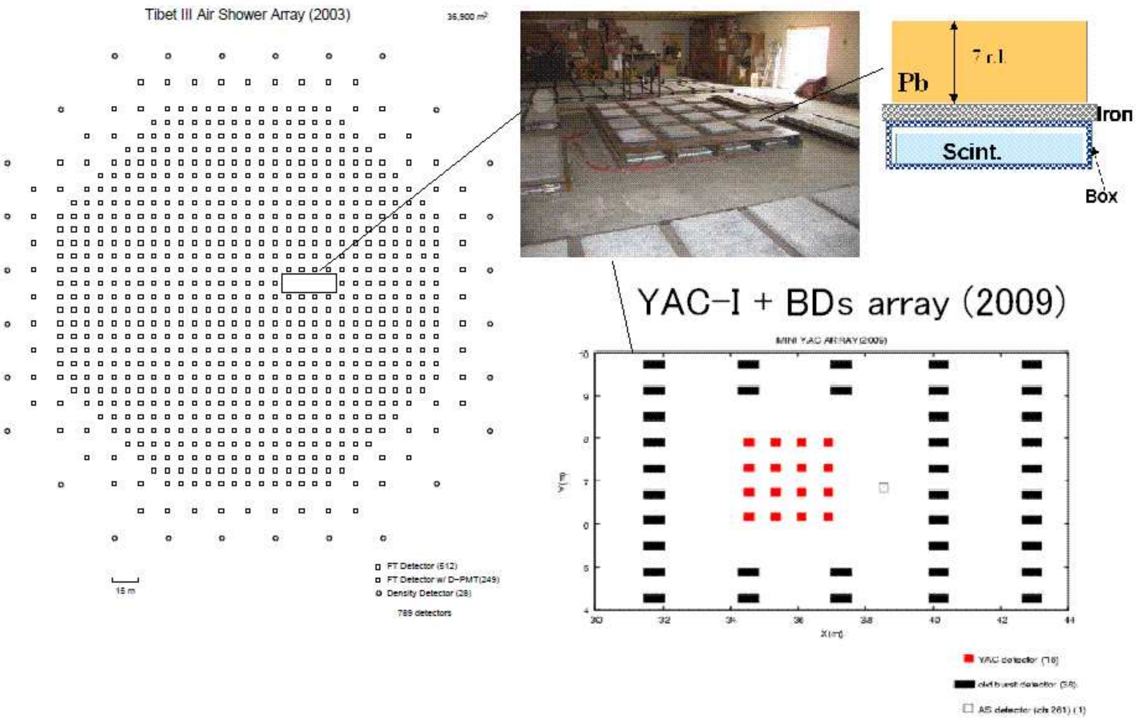


Fig. 1. Schematic view of the Tibet-III air-shower array (Open squares) and the YAC array and BDs (White area)

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In this hybrid experiment, the number of shower particles under the lead plate of a detector unit is called 'burst size' $N_b$. The $N_b$ is defined as the PMT output (charge) divided by that of the single-particle peak, which is determined by a probe calibration using cosmic rays, typically single muons. For this purpose, a small scintillator 25 cm $\times$ 25 cm $\times$ 3.5 cm thick with a PMT (H1949) is put on the top of each detector during the maintenance period. This is called a probe detector [10].

On-line trigger condition for YAC-I detector is set as the burst size $N_b \geq 13$ (discrimination threshold is about 10 mV) any 1 detector. Trigger rate of each detector is 30 Hz approximately. If one YAC-1 detector makes trigger signal, all ADC data from all YAC-I units are recorded. Also the trigger signal is sent to DAQ system for AS array and BD detectors. ADC modules of YAC-I are calibrated every 4 hours. ADC pedestal values are measured every 10 minutes. Each DAQ system has GPS clock module independently. The matching between YAC data and AS data and BDs data is made using coincidence of GPS clocks and trigger tag to AS array. The coincidence condition of GPS is less than 1 ms. The average time difference is 8.1 $\mu$s $\pm$ 0.4 $\mu$s.

The YAC detector was calibrated by using the accelerator beam of the BEPC-LINAC (Beijing Electron Positron Collider-Linear Accelerator). The result of the test-beam experiment will be presented in the near future.

## III. Analysis

Since we have not completed the full detector Monte Carlo simulations, in this paper, we only present the gross features of burst events obtained by using YAC-I experimental data.

In this experiment, the threshold of burst size of a detector unit is set at 100 MIPs (Minimum Ionization Particles). This unit is defind as a 'fired' one. We also call the total burst size of all fired detector units as $\Sigma N_b$, the maximum burst size among fired detectors as ${N_b}^{top}$.

The event selection conditions are set as the burst size $N_b \geq 100$, the number of hit YAC detectors $N_D \geq 4$ and the detector unit with $N_b^{top}$ is located at inner area of BD grid excluding the most outer edges. The last condition is used to reject the detection of the outskirts of the events falling far from the array. From MC simulation [11], it is known that the average primary energy is about 80 TeV under the above selected conditions.

In present paper, we used the data set obtained from April 30, 2009 through May 11, 2009. The effective live time used for the present analysis is 7.875 $\times$ $10^5$ sec. The total number of 'burst events' which is selected under the above conditions is 1124 events from the experimental data.

## IV. Results and discussions

In this paper, we preliminarily show some characteristic features of 'burst-events' obtained by experimental data. In Fig. 2, we present differential $\Sigma N_b$ spectrum of

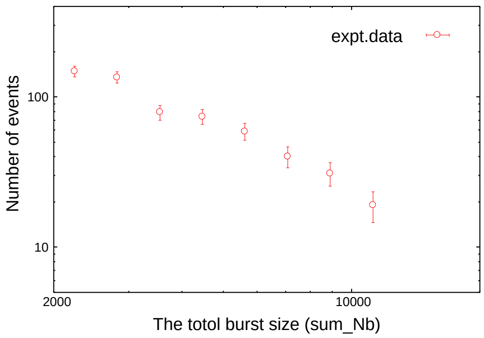


Fig. 2. Differential total burst size ($\Sigma N_b$) spectrum of burst events obtained by YAC-I (preliminary).

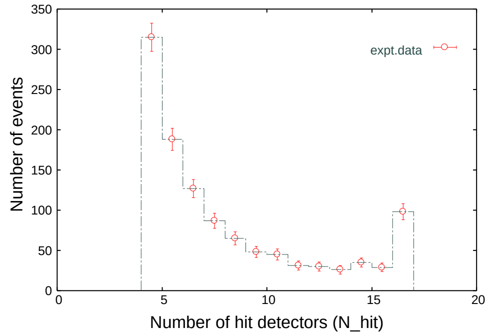


Fig. 4. Distribution of the number of hit YAC detectors ($N_D$) obtained by YAC-I (preliminary).

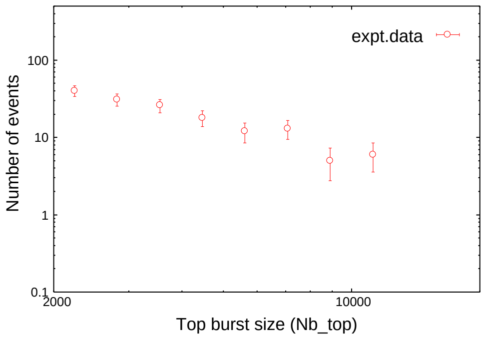


Fig. 3. Differential top burst size (${N_b}^{top}$) spectrum obtained by YAC-I (preliminary).

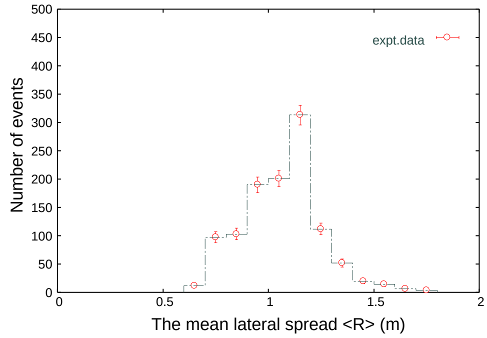


Fig. 5. Distributions of the mean lateral spread ( $< R >$) obtained by YAC-I (preliminary)

'burst-events'. In Fig. 3, we present the distribution of the top burst size $N_b^{top}$ of 'burst-events'. It is well known that the intensity of 'burst-events' depends sensitively on the cross sections, inelasticity, and also on the primary composition [12].

Our another interest is to investigate the lateral characteristics of the air shower core. The number of fired detectors $N_D$ reflects the lateral characteristics of the burst events. The $N_D$ distributions are shown in Fig.4. Fig. 5 shows the mean lateral spread ($< R >= \Sigma r_i/(N_D - 1)$) of each burst events, where $r_i$ and $N_D$ are the lateral distance from the "air shower core" (the position of detector unit having $N_b^{top}$) to a fired detector unit, and the number of hit detectors, respectively. The mean lateral spread ($< R >$) is sensitive to the transverse momentum of secondary particles produced by hadronic interaction.

Therefore, we can check the simulation models compared with experimental results, and provide a check on the modeling in the very forward region. The expected number of 'burst events' which can be selected under the above conditions per half year is estimated as $\sim 2.3 \times 10^4$ events, that is a big sample in statistics.

## V. Summary

From March 2009, YAC-I (Yangbajing Air shower core detector) of approximate 10 m$^2$ was constructed inside the existing Tibet AS array. We have successfully taking data from April 2009. The preliminary data analysis shows that this hybrid experiment (Tibet-AS+YAC-I+BD) is powerful to check the hadronic interaction models used in the AS simulation codes at primary energy around *10 TeV with high statistics.

## VI. Acknowledgements

The collaborative experiment of the Tibet Air Shower Arrays has been performed under the auspices of the Ministry of Science and Technology of China and the Ministry of Foreign Affairs of Japan. This work was supported in part by a Grant-in-Aid for Scientific Research on Priority Areas from the Ministry of Education, Culture, Sports, Science and Technology, by Grants-in-Aid for Science Research from the Japan Society for the Promotion of Science in Japan, and by the Grants from the National Natural Science Foundation of China and the Chinese Academy of Sciences. The support of the Knowledge Innovation Fund (H8515530U1) IHEP, China, to J. Huang is also acknowledged.

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